Process Specification for the Manual Arc Welding of Carbon Steel and Nickel Alloy Hardware

Engineering Directorate

Structural Engineering Division

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REVISIONS		
VERSION	CHANGES	DATE
Baseline	Original version	6/1/95
A	Revised version	10/29/97
B	Formatting, changed process owner, rewrite numerous sections for clarification, deleted requirement for WIR, deleted section 8.2 on audits, added section 8.3 on WPQ, deleted mil specs for NDE, added PRCs for NDE.	07/07/99
C	Comprehensive technical rewrite and reformat, exclude applicability to pressurized hardware, clarify 3.0, add a "D" class weld in 3.1, expand design requirements, add reference to NASA-SPEC-5004 and delete reference to inspection/NDE PRCs, delete Table II, address use of metal cored filler wires in 6.1.2, clarify 6.1.4, specify requirement in 6.4, clarify 6.5 to include weld "rework", expand section 7.0 to clarify, combine 7.2 and 7.3, revise 8.0 to clarify compliance with AWS B2.1, revise all acceptance criteria to clarify and simplify.	9/7/00
D	Comprehensive rewrite to combine PRC-0005 and PRC-0006 and make editorial changes. PRC-0006 will be cancelled with this change. Include requirements for precision cleaned hardware (ref. JPG 5332.1). Expand Class D definition and requirements.	01/28/2004
E	Add reference to good workmanship in section 7.1.4.	03/09/04
F	Add reference to Class D welding in 3.0 for on-site JSC work authorized by the JSC Engineering Directorate's manufacturing operations. Add additional Class D stipulations in last paragraph of 3.1. Added Reviewer signature block.	11/21/2007

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1.0 SCOPE

This process specification provides the minimum requirements that govern the manual arc welding of carbon steel and nickel alloy flight and non flight hardware. Design, procedural and quality assurance requirements are given. All work instructions and Weld Procedure Specifications (WPS) used during welding shall satisfy the requirements of this process specification.

2.0 APPLICABILITY

This process specification applies to manual (and semiautomatic) arc welding of carbon steel and nickel alloy flight and non flight hardware that is fabricated under the authority of NASA/Johnson Space Center (JSC) by any of the following types of welding processes:

a. Gas tungsten arc welding (GTAW).
b. Gas metal arc welding (GMAW).
c. Flux cored arc welding (FCAW).
d. Shielded metal arc welding (SMAW).
e. Plasma Arc Welding (PAW).

The term “flight hardware” refers to any hardware used as a part of a spacecraft, aircraft, or payload. The term “ground based hardware” refers to any hardware made for facilities (buildings and related accessories), ground support equipment, training and mockup mission equipment, engineering prototype and development hardware, and test equipment.

Future builds of hardware where the existing engineering documentation calls out NASA/JSC PRC-0006 for welding shall utilize this specification. Existing hardware fabricated to PRC-0006 requirements shall not be affected by this change. In addition, existing engineering documentation that specifies welding per PRC-0007 shall be accommodated by PRC-0005, Class D. Existing hardware fabricated to PRC-0007 requirements shall not be affected by this change.

3.0 USAGE

This process specification shall be invoked by including a note on the applicable engineering drawing with the following general format which specifies the PRC and weld class nomenclature:

WELD AND INSPECT PER NASA/JSC PRC-0005, CLASS X.

Regarding onsite JSC work for minor facilities repair and manufacture of shop aids that is performed under the work authorization of the JSC Engineering Directorate's manufacturing operations, welds shall be considered Class D, if they conform to the Class D weld criteria and exclusions herein. Execution of these welds shall not require the formality of an engineering drawing, and may be executed by verbal orders.

To minimize fabrication costs by avoiding over-inspection and unnecessary rework/repair, individual welds, or components on a weldment shall be classified separate where possible. This can be accomplished by including a note on the

engineering drawing with the general format shown below which specifies only the PRC nomenclature. The weld class shall then be indicated by either: 1) calling out the specific weld class with the welding symbol at the individual weld joints or, 2) by using specific flag notes with the welding symbol at the individual weld joints. Refer to Figure 3.0a and 3.0b below for examples of these methods.

WELD AND INSPECT PER NASA/JSC PRC-0005. WELD CLASSES SHALL BE AS INDICATED AT WELD LOCATION CALLOUTS.

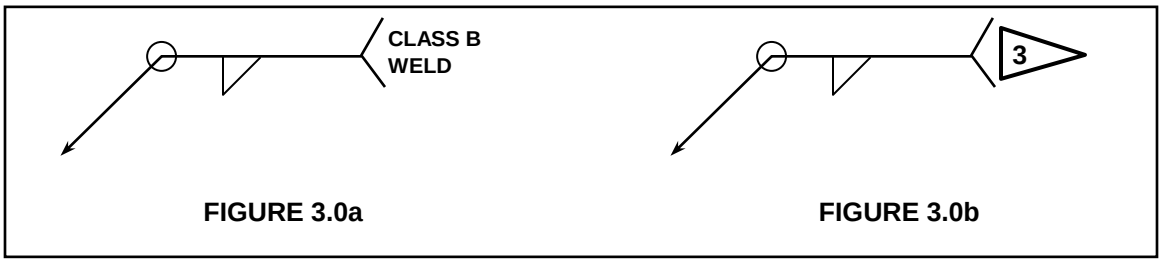

FIGURE 3.0a **FIGURE 3.0b**

3.1 WELD CLASSIFICATION

Welds made using this specification shall be primarily classified in accordance with the service conditions of the weldment. The "Class" governs the extent to which quality assurance provisions are applied to the weld joint.

Alternatively, individual welds, welded connections, or entire weldments (for simplicity, the terms weld, welded connection, and weldment will be used interchangably) may be classified by relating the weld to the factor of safety used in the design. However, when classifying welds in this manner, regardless of the factor of safety, adequate consideration should be given to the severity of the service conditions (e.g., static loading vs. dynamic loading, cyclic, vibration, fatigue, corrosive, extreme temp, etc.), material characteristics (e.g., ductility, toughness, etc.), and the potential consequences of weld failure.

Where conditions exist that make it difficult to choose between 2 weld classes, then the more stringent of the 2 classes shall be applied.

Quality assurance provisions for all weld classes are detailed in Section 7.0. Weld classes shall be chosen on the basis of the following definitions:

a. Class A (Flight or non flight) — Applies to welds in critical load bearing elements that are not fail-safe. Class A welds are typically used in primary load bearing connections. Failure of a Class A weld in service would be catastrophic and would result in the loss of life, system(s), control, or major components. Alternatively, if it is determined from appropriate engineering analyses that a weld has a Factor of Safety (FS_{uts}) vs ultimate tensile strength of the calculated minimum weld throat cross section of <2.0, it shall be designated as a Class A weld.

b. Class B (Flight or non flight) — Applies to welds in load bearing elements that are fail-safe. Class B welds are typically used in secondary load bearing (i.e., shared load) connections. Failure of a Class B weld in service would reduce the overall efficiency of the system, but the loss of the system(s) or endangerment to personnel would not be expected. Alternatively, if it is determined from appropriate engineering analyses that a weld will have a FS_{uts} of ≥ 2.0 and <3.5, it may be designated as a Class B weld.

c. Class C (Flight or non flight) — Applies to welds that are in minor load bearing elements that are fully contained where failure in service would have minor or no affect on the efficiency of a system and endangerment to personnel would not occur. Class C welds are typically used in secondary or tertiary load bearing (i.e., shared load) connections. Alternatively, if it is determined from appropriate engineering analyses that a weld will have a FS_{uts} of ≥ 3.5 and <5.0, it may be designated as a Class C weld.

d. Class D (Non flight hardware only) — Applies to welds that are in noncritical elements and where failure would have no affect on the efficiency of a system and endangerment to personnel would not occur. Class D welds are typically used in connections where any expected load transfer at the weld would be negligible. Alternatively, if it is determined from appropriate engineering analyses that a weld will have a FS_{uts} of ≥ 5.0, it may be designated as a Class D weld. In any case, Class D shall not be specified for welds used for making connections onto critical or primary load path elements (e.g., lift points, etc.) or elements directly related to personnel supporting activities, regardless of the loading condition/direction.

In addition to the above definitions, the following requirements shall also apply to weld classifications:

- If any weld intersects or overlaps another weld of a higher classification, then the lower classed weld shall be automatically upgraded to the higher of the 2 weld classes and subjected to the appropriate quality assurance provisions.
- If any weld falls within ½" of any higher classed weld, then it shall be automatically upgraded to the higher of the 2 weld classes and subjected to the appropriate quality assurance provisions.
- Class D welds are only intended for on-site (JSC) fabrication operations. All welds that are specified as Class D on weldments that are subcontracted off-site shall be recognized as Class C and shall be subject to all applicable Class C requirements specified herein. Class D welds shall only apply to welds made on common "structural" low carbon steels or 300 series CRES steels. HSLA, quenched & tempered steels, and "alloy" (e.g., chromium-molybdenum) steels shall not be considered for Class D welding. In addition, welds joining 2 or more dissimilar base metals shall not be allowable under Class D provisions.

3.2 WORK INSTRUCTIONS

Work instructions shall be generated for implementing this process specification. The work instructions shall contain sufficient detail to ensure that the manufacturing process produces consistent, repeatable results that comply with this specification. At JSC, these work instructions are approved as Detailed Process Instructions (DPIs) that describe in a detailed, step-by-step format the required procedures, equipment, and materials to be used for conducting a given process. If this manufacturing process is to be performed by an outside vendor, work instruction development shall be the responsibility of the vendor.

3.3 DESIGN REQUIREMENTS

a. The design of welded joints (including weld sizes) shall utilize adequate engineering analysis methods (e.g., stress analysis, fracture mechanics/fracture control, etc.) to ensure that the resultant connection strength is capable of successfully transferring the maximum load expected to pass between the interconnecting members and meet the required factors of safety and design margins.

b. All engineering drawings shall depict welded joints using the applicable symbols described in AWS A2.4.

c. The engineering drawing shall specify any additional or alternate testing or inspection requirements. Where spot, intermittent, or other special inspection requirements are specified that deviate from those stated herein, it shall be detailed on the drawing as a note or by using the applicable symbology described in AWS A2.4. For Class A welds, alternate or reduced NDE requirements shall not be allowed.

d. Class A welds are expected to be welds requiring full strength of the weld joint therefore, these welds shall be a groove design and full penetration wherever possible. The ability to successfully perform radiographic examination on these weld joints shall be considered during design.

e. Class A welds which will be subjected to unusual or extreme service conditions (e.g., severe dynamic loading, cyclic, vibration, impact, corrosive, fatigue, extreme temp, etc.), shall be welded using a WPS qualified in accordance with AWS B2.1 “Special Test Weldments.” This requirement shall be noted on the engineering drawing.

f. Unless otherwise specified on the engineering drawing or WPS, welded hardware will be delivered in the “as welded” condition. If required, any heat treatment processing required shall be detailed on the engineering drawing and shall include notation that will reference NASA/JSC PRC-2001 or PRC-2003 as applicable.

g. Intermittent welding (skip welds) shall not be specified for Class A welds.

h. Intermittent welds shall not be specified for groove welds (square or prepared groove design) unless the unwelded portions of the joint are adequately supported to prevent one member from coming out of plane with the adjoining member.

4.0 REFERENCES

The standards listed below shall be considered a part of this specification to the extent specified herein. Unless otherwise indicated, the revision that is in effect on the date of invitation for bids or the date of request for proposals shall apply.

a. American Society of Nondestructive Testing (ASNT)

SNT-TC-1A *Personnel Qualification and Certification in Nondestructive Testing*

b. American Welding Society (AWS) Standards

ANSI/AWS A2.4 *Standard Symbols for Welding, Brazing and Nondestructive Testing*

ANSI/AWS A3.0 *Standard Welding Terms and Definitions*

ANSI/AWS A5.X – A5.XX *Specifications for Welding Electrodes, Rods, and Filler Metals (Applicable to Specific Alloy and Process as governed by this PRC)*

ANSI/AWS B2.1 *Standard for Welding Procedure and Performance Qualification*

ANSI/AWS D1.1 *Structural Welding Code - Steel*

ANSI/AWS D1.6 *Structural Welding Code - Stainless Steel*

ANSIAWS QC-1 *Standard for AWS Certification of Welding Inspectors*

c. Compressed Gas Association, Inc.

G-11.1 *Argon, Commodity Specification for*

d. Federal Documents

BB-C-101 *Carbon Dioxide (CO_2) : Technical and U.S.P.*

BB-H-1168 *Helium Federal Specification*

BB-O-925 *Oxygen, Technical, Gas and Liquid*

e. Military Documents

MIL-A-18455 *Argon, Technical*

MIL-P-27407 *Propellant Pressurizing Agent, Helium*

MIL-P-27201 *Military Specification, Propellant, Hydrogen*

f. NASA/JSC Documents

JPG 5322.1 *Contamination Control Requirements Manual*

PRC-0008 *Process Specification for the Qualification of Manual Arc Welders*

PRC-2001 *Process Specification for the Heat Treatment of Steel Alloys*

PRC-2003 *Process Specification for the Heat Treatment of Nickel Alloys*

SOP-004.5 *Control of Weld Filler Materials, Electrodes, and Fluxing Materials*

SOP-007.1 *Preparation and Revision of Process Specifications*

TI-0000-04 *Training Instruction for the Welding Processes*

g. NASA Headquarters

NASA-SPEC-5004 *Welding of Aerospace Ground Support Equipment and Related Nonconventional Facilities*

5.0 MATERIAL REQUIREMENTS

All materials (base and filler materials as applicable) used in the welding of hardware per this specification, shall meet the requirements of an applicable JSC material specification unless otherwise specified. If a JSC material specification is not available, then an applicable commercial specification or a manufacturer's specification shall be used.

5.1 SHIELDING GASES

Allowable shielding gases (including purge gases) are listed in Table I. Gases purchased to alternate specifications shall be allowed provided they meet the minimum requirements of the specifications listed herein. Mixtures of these gases are allowed and the nominal mixture used for the qualification welding shall be that used for production and shall be listed on the WPS. Shielding and purging gas mixtures shall be subject to the qualification variable requirements listed in AWS B2.1. In addition:

a. Hydrogen gas in any concentration, may not be used for welding any alloys known to be susceptible to hydrogen related problems (e.g., alloy steels, Q&T steels, martensitic stainless steels, etc.).

b. Nitrogen shall not be used for shielding or purging in any welding operation governed under this specification.

c. All gases used for shielding or purging shall have a dewpoint of -40°F (minus 40 °C) or better.

5.2 FILLER METALS AND ELECTRODES

All filler metals shall meet the requirements of the applicable AWS filler metal specification relative to the specific alloy and process being used. Filler metals shall be selected from Tables II, III, and IV. If designated in **BOLD TYPE**, this shall be the first choice for filler metal. Otherwise, selection shall be based on specific base metal combinations, service environment, etc.). Tubular sleeve and filler insert materials shall have compositions similar to those indicated in Tables II, III, and IV. In addition, the following shall apply:

a) For dissimilar metal welds joining carbon steel to low alloy steel, or between two different low alloy steels, filler metal with strength levels matching the lower strength material shall be used. For dissimilar metal joints involving stainless and corrosion resistant steels, nickel alloys, and/or other materials, filler metal selection shall be based on that stated herein and approved by the NASA/JSC M&P organization prior to use.

b) All filler metals shall be used in accordance with a qualified WPS.

c) Filler metal configurations which can not be procured to an AWS or other applicable filler metal specification shall meet an applicable NASA/JSC or other industry material specification and shall be approved by the NASA/JSC M&P organization prior to use.

d) Non consumable tungsten and tungsten alloy electrodes for GTAW and PAW shall conform to the applicable AWS specification.

e) Filler metals shall be listed on the engineering drawing.

Table I. Allowable Shielding Gases

GAS	DESCRIPTION	SPECIFICATION
Argon	Gas	MIL-A-18455
Argon	Type II, Grade B (Liquefied)	CGA G-11.1
Carbon Dioxide	Grade B	BB-C-101
Helium	Type I, Grade A	MIL-P-27407
Hydrogen	Gas	MIL-P-27201
Oxygen	Type I	BB-O-925

Table II. Approved Filler Metals for Welding Carbon and Low Alloy Steel

MATERIAL GROUP	SMAW	GTAW / GMAW and PAW	FCAW
M-1	A5.1: E60XX, **E70XX** or A5.5: E70XX-A1 (a)	A5.28: E70S-2, E70S-3, **E70S-6**	A5.22: **E70T-1**, E70T-5
M-3	A5.5: E70XX-A1	A5.28: **ER80S** / E80C-D2	(b)
M-4	A-5.5: E80XX-B2	A5.28: **ER80S**,E80C-B2, ER80S / E80C-B2L	(b)
M-5 (3% Cr max)	A5.5: E90XX-B3	A5.28: **ER90S**, E80C-B3, ER90S / E90C-B3L	(b)

Notes:

(a) A5.5, E70XX-A1 shall be used for materials with maximum specified carbon greater than 0.30%.

(b) Filler metal to be used for joining must be compositionally compatible with base metal. Primary consideration shall be given to mechanical properties, corrosion resistance, and weldability, as applicable for the specific application.

Table III. Approved Filler Metals for Welding Nickel Alloys

BASE METAL	SMAW (AWS A5.11)	GTAW / GMAW / PAW (AWS A5.14)
Nickel 200 **Nickel 201**	ENi-1	ERNi-1
Monel 400	ENiCu-7	ERNiCu-7
Monel K500	--	ERNiCu-7
Inconel 600	**ENiCrFe-1**, ENiCrFe-3	**ERNiCrFe-5**, ERNiCr-3
Inconel 601	**ENiCrFe-3**, ENiCrMo-3	**ERNiCr-3**, ERNiCrMo-3
Inconel 625	ENiCrMo-3	ERNiCrMo-3
Inconel 718 **Inconel X750**	--	ERNiFeCr-2
Incoloy 800	**ENiCrFe-2**, ENiCrCoMo-1	**ERNiCr-3,** ERNiCrCoMo-1
Incoloy 800HT	ENiCrFe-2	ERNiCr-3
Incoloy 825	--	ERNiFeCr-1

Table IV. Approved Filler Metals for Welding Austenitic Stainless Steel

AWS M-8 Base Metal:	304 308	304L	309	310	316	316L	321 347 348
301 **302** **304** **308**	308 **308L**	308 **308L**	308 308L 309 **309L**	308 308L 309 **309L** 310	308 308L 316 **316L**	308 308L 316 **316L**	308 **308L**
304L	308 **308L**	**308L**	308 308L 309 **309L**	308 308L 309 **309L** 310	308 308L 316 **316L**	308L **316L** 309L	**308L** 347
309			309 **309L**	309 **309L** 310	309 309L 316 **316L**	309 309L 316 **316L**	309 **309L** 347
310				310	316 **316L** 310	316 **316L** 310	308 308L **310**
316					316 **316L**	316 **316L**	308 308L 316 **316L**
316L						309L **316L**	309L **316L**
321 **347** **348**							309L 321 **347**

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5.2.1 Control and Storage

Welding electrodes shall be stored in a clean, dry, and controlled area that provides protection from contamination, physical damage, and commingling of alloys. Any form of electrodes or weld filler metal which is damaged, dirty, exhibits oxidation/corrosion or has been contaminated with water, oil, grease or any form of hydrocarbons shall not be used and shall be disposed of in accordance with an appropriate disposal procedure. For JSC operations, welding electrodes and filler materials shall be controlled in accordance with EM-004.5. Outside vendors shall provide control and storage according to the applicable material specification or manufacturer's recommendation, whichever is more rigid.

6.0 PROCESS REQUIREMENTS

All weldments shall be fabricated according to the requirements of this process specification and shall be performed using Welding Procedure Specifications (WPS) that have been qualified in accordance with the requirements of Section 8.1 except for that as detailed below.

Class D welds may be performed without the use of a specific qualified WPS within the following restrictions:

a) all other provisions of this specification are met,

b) the filler metal/electrodes used shall be within the same F-Number group of fillers as those used for the other higher classed welds in the same weldment or as approved by the responsible M&P Engineering organization where the only welds in the weldment design are Class D,

c) the filler metal shall be compositionally compatible with the base metal(s), and

d) welding shall be conducted within the recommendations of the specific filler metal manufacturer.

6.1 WELDING PRECISION CLEANED HARDWARE (including tube preparation for welding)

Whenever precision-cleaned hardware must be maintained clean during welding into an assembly, the welding operation shall be performed in a dedicated Class 100,000 Clean Work Area. This may require temporary tents over the weld area and/or local monitors located in the area of welding to ensure the Class 100,000 environment is being met. Portable particle counters shall be located as close as possible to the work area, so as to monitor local contaminants during tube preparation and welding. Tools used in weld preparation and welding (such as cutter, weld head, files) shall be visibly cleaned per JPG 5322.1 and maintained clean (e.g. bagged when not in use).

For hardware that cannot be subsequently precision-cleaned, a proven method for protecting against system contamination during tube preparation and welding shall be implemented. One such method is the use of a physical barrier, such as plugs. The

installation and removal of plugs shall be tracked by a reliable method and independently verified. Prior to plug removal, the exposed internal surfaces of the tube shall be cleaned using a swab wetted with an approved solvent, and positive backpressure shall be maintained as the plug is removed.

Tube cutters shall use a sharp blade, changed frequently. Cutting shall be performed with minimal cutter pressure to aid in preventing particle generation. Vacuum shall be used during tube facing operations to remove particulate. Whenever possible, facing operations shall be performed away from the weld assembly area, to reduce particulate contamination of the welding work area. Tube facing shall be performed without the use of cutting oils, other fluids, lubricants or coolants. Abrasives, including sandpaper or abrasive pads, shall not be used inside tubes or when unprotected internal surfaces are exposed. After each tube preparation, and prior to welding, a high-velocity gas purge shall be performed. The purge gas velocity shall be the maximum attainable using a 90-psig source. The purge gas used during facing and welding shall meet the hydrocarbon and particulate requirements for the system under assembly. The purge gas shall be supplied in accordance with Section 5.1.

6.2 PROCESS-SPECIFIC REQUIREMENTS

Applicable to all processes, weld joints that are specified for intermittent welding shall have the ends of the parts, or departure from a straight weld line (e.g., square corner, etc.), welded regardless of the interval of the weld.

6.2.1 Gas Tungsten Arc Welding

Additional filler metal shall be used with the GTAW process unless it can be demonstrated by weld qualification that weld cracking and other undesirable metallurgical conditions will not exist in the finished weld made without filler metal (autogenous weld). This method of welding shall be specified on an approved WPS.

6.2.2 Gas Metal Arc Welding

This process shall be recognized to include both solid and metal cored wires.

The GMAW short circuiting transfer mode shall not be used for welding of flight hardware nor to join materials of greater than ¼" thickness unless specifically qualified and documented in a WPS. Thickness limitations for this process mode shall be as specified by AWS B2.1. The process can be used to deposit the root and additional passes in the root region of butt joints exceeding that specifically qualified for, up to a deposited weld metal thickness as allowed by the WPS. The GMAW short circuiting transfer mode shall not be used to make Class A welds.

6.2.3 Flux Cored Arc Welding

This process shall be recognized to include both self shielding and dual shielding filler metals.

6.2.4 Shielded Metal Arc Welding

Base metals known to be susceptible to hydrogen related problems shall utilize only low hydrogen coated electrodes with this process.

6.2.5 Plasma Arc Welding

Additional filler metal shall be used with the PAW process unless it can be demonstrated by weld qualification that weld cracking and other undesirable metallurgical conditions will not exist in the finished weld made without filler metal (autogenous weld). This method of welding shall be specified on an approved WPS.

6.3 PREHEATING

Preheat shall not exceed the temperature specified in the applicable WPS. In weld joints between different base metal types and/or thicknesses, the higher of the preheat requirements of the joint members shall apply.

6.3.1 Interpass Temperature

In weld joints between different base metal types and/or thicknesses, the higher of the interpass temperature requirements of the joint members shall apply. Minimum interpass temperature during welding shall be the same as the preheat temperature specified in the WPS and shall be maintained by the application of concurrent heat as necessary. The maximum interpass temperature for welding quenched & tempered steels shall be at least 50^{o} F below the nominal tempering temperature.

6.4 POST-WELD HEAT TREATMENT (PWHT)

Postweld heat treatment, when required by the engineering drawing or WPS, shall be performed after completion of all welding in accordance with NASA/JSC PRC-2001 or PRC-2003, as applicable. Vibratory techniques shall not be used in place of thermal treatments. All postweld inspections shall be applied immediately following all post weld heat treatment activities with the exception of ASTM A514, A517, and A709 Grades 100 and 100W. Inspection of welds made on these alloys shall not occur less than 48 hours after welding.

6.5 WELD REPAIRS AND WELDED REPAIRS TO BASE METAL

All weld rework and welded repairs shall be performed using the WPS used for the original weld, a specific qualified WPS for that repair, or as approved by the responsible M&P engineering organization. Rework and repairs shall meet all of the requirements of the original drawing and any additional requirements documented in the WPS. Weld rework and repair does not include the correction of dimensional or other deficiencies of the groove/bevel preparation of weld joints by “buttering” or build up provided the area corrected by welding is fully consumed in the final weld. Also, the following requirements shall apply in the weld repair activity:

a. Defect Removal. Defect removal shall be by means of grinding, chipping, machining, thermal gouging or a combination of these methods. Except on low carbon steels, thermal gouging, and cutting performed with carbon based

electrodes shall require the excavated cavity be finished by grinding to sound metal. The final repair cavity shall be of a configuration suitable for welding. The excavation shall be subjected to visual and/or other NDE examinations to ensure defect removal prior to welding. Weld repairs shall be adequately documented by the use of a weldment map or other record with sufficient detail to ensure identification of the weldment, identification of repair location(s), and type of defect.

b. Repair. No more than two weld attempts shall be made to successfully repair a rejected flaw. If a second attempt is unsuccessful, a discrepancy report shall be generated and shall require dispositioning by the responsible Material Review Board (MRB). The level of documentation of repair welds shall, at a minimum, be consistent with that required for the original production weld.

c. Straightening. Welds or adjacent base metal which have been deformed by the welding operation may be straightened. All straightening operations shall take place at temperatures not to exceed the determined critical temperature for that alloy. All straightening operations shall be performed prior to any final inspection.

d. Base Metal Repairs. Repairs to base metal anomalies shall be brought to the attention of the NASA/JSC M&P organization for consideration of cause, prior to repair activities.

7.0 PROCESS VERIFICATION

Process verification shall consist of nondestructive examination(s) (NDE), as described in sections 7.1 to 7.3. In addition, the manufacturer shall assure that the fabrication activities are carried out in a manner that meets the requirements of this process specification.

7.1 INSPECTION

Unless otherwise specified in design documentation, all inspections (examinations) detailed herein are required to include all welds in a structure. Any temporary welds, unconsumed tack welds, etc. shall be subjected to the level of inspection required by the highest weld class specified on the design documentation.

7.1.1 Class A Inspection

a) Class A welds require visual (VT), surface, and subsurface NDE. Surface inspections shall be accomplished using the liquid penetrant (PT) or magnetic particle (MT) inspection process and shall be performed per AWS D1.1 for carbon and low alloy steels and AWS D1.6 for all other alloys welded to this specification. Unless otherwise specified, PT shall utilize Type I, Level 3 or 4 and MT shall utilize the wet fluorescent continuous method. Results of all surface inspections for Class A joints shall utilize the Class A acceptance criteria in Appendix A. Subsurface inspections shall be accomplished using the radiographic (RT) inspection process and shall be performed per AWS D1.1 for carbon and low alloy steels and AWS D1.6 for all other alloys welded

to this specification. In either case, unless otherwise specified, the acceptance criteria shall be as listed for “Cyclically Loaded” tension welds (and “Tubular” or “Nontubular” connections as applicable for conditions subjected to AWS D1.1) in each applicable AWS code.

b) In cases where the Class A inspection is designated for any weld having a configuration which renders adequate RT methods impractical, an alternate examination method shall be utilized as approved by the responsible NASA/JSC M&P engineering organization.

c) When the PT method is selected and approved as a complete alternate to RT for multipass welds, inspections shall be performed on the root pass, each 1/4” thick layer of weld metal, and the final or cover pass.

d) When the ultrasonic (UT) inspection method is selected as an alternate to RT, it shall be performed per AWS D1.1 for carbon and low alloy steels and AWS D1.6 for all other alloys welded to this specification. In either case, unless otherwise specified, the acceptance criteria shall be as listed for “Cyclically Loaded” tension welds (and “Tubular” or “Nontubular” connections as applicable for conditions subjected to AWS D1.1) in each applicable AWS code.

7.1.2 Class B Inspection

Unless otherwise specified in design documentation, Class B welds require VT and surface NDE only. Surface inspections shall be accomplished using the PT or MT inspection process and shall be performed per AWS D1.1 for carbon and low alloy steels and AWS D1.6 for all other alloys welded to this specification. Results of all surface inspections for Class B joints shall utilize the Class B acceptance criteria in Appendix A. Unless otherwise specified, PT shall utilize Type II and MT shall utilize the dry continuous method.

7.1.3 Class C Inspection

Unless otherwise specified in design documentation, Class C welds require VT only. Results of all VT inspections for Class C joints shall utilize the Class C acceptance criteria in Appendix A.

7.1.4 Class D Inspection

Unless otherwise specified in design documentation, Class D welds require only inspection to verify the type, nominal size, length, location, and that the welds were left in a condition exhibiting good workmanship practices. Good workmanship shall be defined as the presence of uniform appearance and overall clean weld zones and the absence of spatter, arc strikes, tool marks, and other obvious discontinuities that would likely be questionable. Where a size is not specified, the nominal weld size shall be per best shop practice and at the discretion of the manufacturing organization with the intent to utilize single pass welds wherever possible so as to avoid over-welding. A CWI is not required for this inspection. This level of inspection may serve as a means of “in process” or “self verification” where design and/or manufacturing protocols permit.

7.2 VISUAL EXAMINATION REQUIREMENTS

All visual inspections (VT) of Class A, B, and C welds shall be performed by an American Welding Society (AWS) Certified Welding Inspector (CWI). The CWI certification must be current. Inspection of Class D welds do not require a CWI.

7.3 NON-DESTRUCTIVE EVALUATION (NDE)

The NDE of welded joints shall be performed by personnel qualified in accordance with the requirements of the applicable NDE process specification. The NDE certification must be current. All nondestructive inspections shall be performed in accordance with the appropriate standards as referenced herein.

8.0 PROCESS DOCUMENTATION REQUIREMENTS

The WPS, PQR, and WPQ shall be prepared and retained as a permanent record and made available upon request to the NASA/JSC M&P organization for review. One copy of the WPS shall be maintained in the vicinity of the welding station and shall be readily accessible by the welding, inspection, supervision, and engineering personnel.

8.1 WELDING PROCEDURE SPECIFICATION

A Welding Procedure Specification (WPS) is a qualified written working procedure used in production that must be developed before beginning production for each unique weld type to be produced. Qualification support documentation in the form of a Procedure Qualification Record (PQR) shall be qualified by appropriate testing and maintained on file to show proof of process/procedure capability for using the WPS. The WPS shall be traceable by means of serialized nomenclature and shall show traceability to the applicable PQR(s). The WPS used for production welding shall meet the requirements of AWS B2.1 and shall be certified by the responsible M&P organization at the operating facility, prior to use in production. If a qualified WPS does not exist prior to welding of production parts, one shall be qualified according to AWS B2.1 “Standard Test Weldments”, at a minimum.

8.2 PROCEDURE QUALIFICATION RECORD

A Procedure Qualification Record (PQR) is documentation to support the WPS to show proof of process/procedure capability. A PQR shall be unique and traceable, by means of serialized nomenclature. The PQR shall be process-specific and specific to a unique weld type. The PQR shall meet the requirements of AWS B2.1 and shall be certified by the responsible M&P organization at the operating facility.

8.3 WELDER PERFORMANCE QUALIFICATION

A Welder Performance Qualification (WPQ) is documentation showing that a welder has been tested in accordance with the governing specification and shown competent to produce a sound weld for a specific welding process/base metal/filler metal/position combination. NASA/JSC PRC-0008 is the governing document for personnel performance qualifications required by this specification.

9.0 TRAINING AND CERTIFICATION OF PERSONNEL

9.1 TRAINING

At JSC, if welder training is considered necessary prior to qualification/requalification of existing JSC welding personnel or for the initial qualification of new hires, it shall be conducted in accordance with TI-0000-04. For an outside JSC vendor, welder training (when necessary) should consist of practice using the facility welding equipment and a specific WPS to demonstrate proficiency, under the supervision of a qualified/certified welder. Specific development of an appropriate training program shall be the responsibility of the vendor.

9.2 WELDER QUALIFICATION

Welding shall be performed by a welder qualified and certified in accordance with NASA/JSC PRC-0008. Sufficiently detailed records shall be maintained to demonstrate continuity of performance qualification on a semi-annual (6 month) basis.

10.0 DEVIATIONS AND WAIVERS

Any deviations or waivers regarding the use of this process specification shall be requested in writing. This request shall be directed to the NASA/JSC M&P organization with the appropriate justification and rationale. A written response will be provided upon such a request.

Appendix A

WELD INSPECTION CRITERIA

GENERAL If any of the inspection conditions listed herein conflict with the requirements of the engineering drawing, then the more strict criteria shall govern. Pertinent to this Appendix, the designation 'T' shall mean the nominal base metal thickness of the thinnest component in the welded connection. Unless otherwise stated, the criteria in this Appendix shall apply to all weld classes except Class D. Acceptance criteria for Class D welds is detailed only in Section 7.1 of this specification. Alternate and/or additional acceptance criteria may be used for any weld class however, it shall be specified in the design documentation.

A1.0 SIZE AND APPEARANCE

A1.1 GROOVE WELDS

All Classes - The minimum weld size shall be the size (i.e., size = effective weld throat) specified on the drawing. If profile requirements are not specified, the weld shall be convex or flat. Weld profile requirements do not apply at the ends of groove welds provided any concavity is gradually sloped and evidence of good workmanship exists in regards to weld terminations. Where a size is not specified, the penetration requirement shall be 100%. Reinforcement requirements shall be as specified below.
Class A - If profile requirements are not specified, the weld shall be convex.

A1.2 FILLET WELDS

All Classes - The minimum weld size shall be the size specified on the drawing (i.e., size = leg size). If profile requirements are not specified, the weld may be slightly concave, flat, or convex. However, concave profiles shall have at least the minimum throat for the size of weld specified. Weld profile requirements do not apply at the ends of fillet welds provided any concavity is gradually sloped and evidence of good workmanship exists in regards to weld terminations. For intermittent welding, the ends being exempt from these profile requirements shall be outside the specified effective weld length. Where a size is not specified, the weld size shall be a minimum of 75% of the thickness of the thinner component. Reinforcement requirements shall be as specified below.
Class A and B - The weld size may fall below the size specified by up to 1/16" or T/4, whichever is less, for 10% of the total weld length (1).
Class C - The weld size may fall below the size specified by up to 1/16" or T/3, whichever is less, for 30% of the total weld length (1).

(1) The weld length shall be the distance from end to end of the weld deposit or to a sharp change in direction of the weld where the angle of change in any direction is greater than 30 degrees at a radius of <1/2".

A2.0 WELD REINFORCEMENT

A2.1 GROOVE AND FILLET WELDS

Weld reinforcement (face and root) shall not exceed that specified in Table A2.1a.

TABLE A2.1a – Weld Reinforcement Height Limits

Weld Face Width	Reinforcement Height
≤ ¼"	1/16"
¼" < and ≤ ¾"	1/8"
¾"< and ≤ 1-3/4"	3/16"
> 1-3/4"	¼"

A3.0 MISALIGNMENT AND PEAKING (angular misalignment)

Class A - Misalignment shall not exceed T/10 or 1/8", whichever is less. Peaking shall not exceed 3^{O}.
Class B - Misalignment shall not exceed T/5 or 3/16", whichever is less. Peaking shall not exceed 5^{O}.

Note - Where both misalignment and peaking exist as a combined condition in the same weld, either of the 2 conditions must not exceed ½ that stated above in order to be determined to be acceptable.

A4.0 SURFACE DISCOLORATION AND OXIDATION

Weld zones shall not exhibit a burned appearance or contain loose oxidation or scale attributable to atmospheric contamination.

A5.0 SURFACE ROUGHNESS

Class A and Class B – On mechanically dressed (e.g., ground, sanded, etc.) weld and adjacent surfaces within ½" of the weld toe, surface roughness shall not exceed 125 μin.

A6.0 DISCONTINUITIES

All Classes - Weld discontinuities exceeding the maximum allowable sizes for the applicable Class in Table A6.0 shall not be allowed. Elongated discontinuities shall be defined as having a length to width ratio of ≥ 3:1. Rounded discontinuities shall be defined as having a length to width ratio < 3:1.

For base metal thicknesses (T) ≥ 1/8", the following shall apply to Table A6.0a:

Class A - Any discontinuity, except cracks and undercut, <0.01" at its greatest dimension, shall not be considered.
Class B - Any discontinuity, except cracks and undercut, <1/32" at its greatest dimension, shall not be considered.
Class C - Any discontinuity, except cracks and undercut, <1/16" at its greatest dimension, shall not be considered.

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TABLE A6.0 - Maximum Allowable Discontinuity Sizes

LINE ITEM	DISCONTINUITY TYPE	Class A	Class B	Class C
1	**Cracks in the weld or base metal (e.g., longitudinal, transverse, crater, toe, etc.)** (1)	None allowed	None allowed	None allowed
2	**Undercut Depth** (1)	0.01" or 0.1T, whichever is less	1/32" or 0.33T, whichever is less (3)	1/16" or 0.33T, whichever is less (3)
3	**Arc Strike**	None allowed	None allowed	n/a
4	**Spatter**	None allowed	None allowed	n/a
5	**Elongated** (1)	None allowed	3/32" or 0.4T in length, whichever is less (4) Sum of all visible indications shall be ≤3/8" or T in length, whichever is less, in any 1" of weld length and ≤3/4" in any 12" of weld length (5)	1/8" or 0.6T in length, whichever is less (4) Sum of all visible indications shall be ≤1/2" in length, in any 1" of weld length and ≤1.75" in any 12" of weld length (5)
6	**Rounded** (1)	Surface: 1/16" or 0.3T diameter, whichever is less (2)	3/32" or 0.4T diameter whichever is less (2) Sum of all visible indications shall be ≤3/8" or 1.5T in length, whichever is less, in any 1" of weld length and ≤3/4" in any 12" of weld length (5)	1/8" or 0.6T diameter, whichever is less (2) Sum of all visible indications shall be ≤1/2" in any 1" of weld length and ≤1.75" in any 12" of weld length (5)

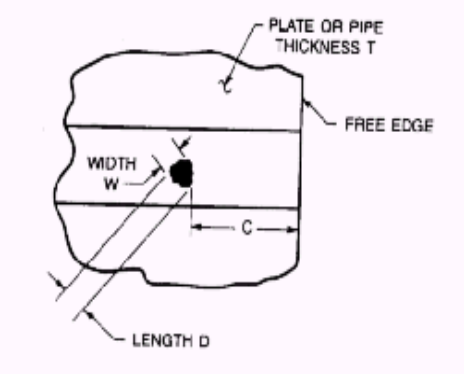
(1) For all discontinuities approaching a free edge (See Figure A6.0 below) that are being considered, the closest edge of the discontinuity shall have clearance from the free edge ≥ 3X the largest of its dimensions or, ≥ 2X the nominal weld throat, whichever is greater.

(2) Adjacent rounded discontinuities separated by ≤ 1X the length of the longer discontinuity shall be considered a single discontinuity.

(3) Undercut may be 2X the value permitted, but never to exceed 1/16", for a continuous or accumulated length of 2" in any 12" weld length or 15% of the total weld length where the weld length is less than 12".

(4) Adjacent elongated discontinuities separated by ≤ 3X the diameter of the larger discontinuity, shall be considered a single discontinuity.

(5) For weld lengths less than 12", the total sum of indications shall be an equivalent proportion of the weld length, to that given.



C = Clearance spacing between closest edge of discontinuity and free edge

FIGURE A6.0 – DISCONTINUITY APPROACHING FREE EDGE

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